Stratospheric Balloon Missions for Planetary Science:
A Petition for the Formation of a Working Group to Study the Feasibility of a Facility Platform to Support Planetary Science Missions

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I. Our Vision

A high-altitude balloon (HAB) capability will enable an era of low-cost planetary science missions. To that end, we propose:

1) The formation of a NASA-funded working group to study the application of HAB to planetary science problems.
2) The funding of a design study to produce a common HAB bus capable of supporting a variety of instruments and observing scenarios.

We emphasize the high-altitude capability of NASA's SMD balloon program because it is this capability that enables planetary science investigations. We propose to develop a plan for an upper stratospheric observatory that would augment and provide new capability to current ground-based and airborne platforms available to planetary science. The outcome of this activity will be an assessment of the cost/benefit of the HAB program compared to the costs of current resources as well as a science roadmap that will articulate the new science and potential for discoveries enabled by HAB.

Because many planetary science investigations have similar measurement requirements, a single platform design can meet the needs of a large number of researchers and mission goals, increasing the number of participants in NASA missions and providing new science results either not available from current platforms or at a lower cost than space-based or current airborne assets. Recent advances in pointing, stability, landing risk mitigation, available telescopic aperture size, and mission duration provide the potential for repeated use, superior observations compared to ground-based and aircraft platforms, and at lower cost. The development and use of a standard platform that includes the gondola, telescope (possibly), precision pointing, data storage and related electronics with a standard instrument interface, would result in:

- Lower costs by eliminating platform development for each balloon mission. Currently each new proposed mission requires a platform design.
- Provide access to new science and mission involvement to a large number of new researchers and students, enabled by not requiring each research group to develop a new gondola.
- Mitigate operational risks currently associated with gondola development by individual research groups. This will revitalize the science while reducing proposal costs by opening the opportunity while reducing schedule, cost, and mission risk.
- Significantly shorten the development time for each funded effort for which only instrument development and integration into the existing platform bus would be required.
- Leverage the experience and technology development currently underway within the NASA Balloon Program.

Together, this positive feedback can result in a vibrant cadence of planetary science balloon missions. The goal of this white paper is to petition for the establishment of a high-altitude balloon program within the Planetary Science Division (possibly in conjunction with the current SMD balloon program) and the study and development of a reusable, standardized platform to support planetary science missions.

II. NASA Balloon Facility Overview

"The primary objective of the NASA Balloon Program is to provide high altitude scientific balloon platforms for scientific and technological investigations" – NASA Balloon Program Mission Statement. Unmanned helium balloons have provided NASA with an inexpensive means to place payloads into a space environment (approximately 120,000 ft or >35 km) since 1990, with as many as three flights per year from Antarctica, several flights from the continental US and Australia, and now several long-duration flights/year from Sweden. Both long-duration (1 – 4 weeks) and short-duration (~ 3 – 7 days) flights exist. Many important scientific observations in fields such as hard x-ray/gamma-ray, infrared astronomy, cosmic rays and atmospheric studies are currently made from balloons. The long durations (> 2 – 4 weeks norm) are enabled through unique atmosphere circulation during the summer allowing scientists to launch balloons from a site near McMurdo Station in the southern hemisphere, and from Kiruna, Sweden, in the northern hemisphere. The polar vortex, a persistent, large, low-pressure system results in very little atmosphere or temperature change during these constant daylight observations, providing excellent optical observing conditions in addition to being high enough that the full electromagnetic spectrum, other than the deep ultraviolet, is available.

III. Augmenting Current NASA Capabilities at Low Cost

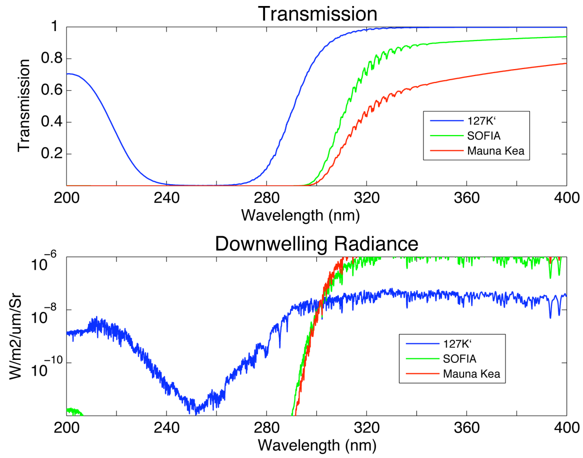
A balloon program within SMD that provides a multi-mission platform to support planetary science at a low cost – approximately equivalent to operating costs of ground-based observatories – would augment and provide measurement capabilities unavailable to current ground-based and airborne telescope facilities owing to its location in the upper stratosphere. Importantly, a dedicated balloon facility capability would provide a far larger amount of observing time to planetary science than currently available. For example, two 2-week long missions on a balloon platform would provide as many observing hours for solar system observations as SOFIA will be able to allocate to ALL observing over the entire year – about 1000 hr [Sofia Science Vision, p. ix]. Secondly, the combined development and operation cost for a multi-mission HAB would be less than that of a large telescope. Gondola and telescope development typically run several million dollars. A single 20-day flight equates to ~ $275K/day, compared to the ~ $47K/night (TSIP webpage) of a large ground-based telescope. However, within five flights the expense of operating HAB is lower if the costs of platform refurbishment are minimized.

IV. Science Opportunities for HAB

Operation from high altitude, where the atmosphere is largely unabsorbing to electromagnetic radiation and is also photometrically stable, opens up the realm for new science measurements that are not as well performed, or impossible, from ground-based platforms and even airborne platforms. At 36 km, reduced telluric contribution will improve spectral contrast of bands in wavelength ranges that are absorbing at lower altitudes, potentially enabling the discovery of shallow absorption bands or removing the dependence on Doppler shifting to enable an observation. The upper atmosphere is also more uniform, making corrections for remaining telluric effects more precise than those at lower altitudes.

Although space-borne observatories (e.g. JWST) can be well-suited for these measurements, they tend to be a limited resource for solar system science, whereas balloon missions could provide a list of high-value targets. The atmospheric transmission at float altitude is also significantly better than at SOFIA altitudes for UV, NIR, and TIR wavelengths. Furthermore, the line-of-sight column sampled by SOFIA is swept along at aircraft speeds, potentially resulting in large and fast temporal variations, and the image stability of its exposed 2.5-m telescope is currently unknown compared to high-altitude balloons that float at equilibrium with no rapid atmospheric variations or platform vibrations.

NUV Partly Accessible at 36km



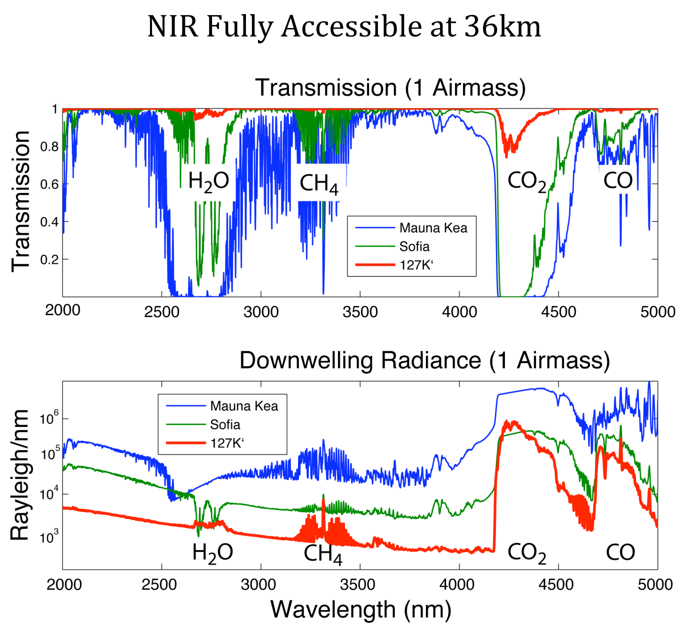
The near UV from ~ 195nm to 225nm and from 280nm and longward are available at high altitude. The lack of Rayleigh scattering suggests daytime observations are potentially feasible in addition to nighttime observations.

Below are examples of science missions enabled by HAB and associated estimated measurement requirements, broken up by relevant portions of the electromagnetic spectrum. Many additional mission concepts can take advantage of these newly available or improved observation conditions within and throughout these regions of the spectrum.

<u>Near-Ultraviolet (partial 200 – 350 nm)</u>: High-altitude balloons can raise telescopes above much of the UV-blocking atmosphere, enabling near-ultraviolet (NUV) observations of solar system bodies (200-350 nm). A combination of O_3 and O_2 prevent NUV measurements from the ground or SOFIA. However at 36 km, the absorption in the Hartley and Huggins bands of O_3 becomes narrow so that longward of 280 nm becomes available, as do wavelengths shortward of 220 nm until the Shumann-Runge band in O_2 begins just below 200 nm. Additionally, seeing is improved throughout the NUV because Rayleigh scattering, which plagues platforms at lower altitudes, is absent.

1. Small Bodies. Objects that could potentially be observed from a balloon-mounted UV telescope include small bodies such as comets, asteroids, and “high risk” targets such as Mercury and sun-grazing comets. Near-sun observations are particularly facilitated because both ground-based telescopes and space-based telescopes often have pointing restrictions prohibiting these measurements (SOHO being an exception).

2. Planetary and Cometary Atmospheres. The 200-310-nm NUV region enables the observations of planetary aurora and atmospheric components. The key features are OH emissions, atomic oxygen at 297 nm, CO_2 UV doublet and FDB bands, CO Cameron bands, NO and N emissions, SO and SO_2, as well as H_2 emissions. The ability to observe from a point above the Rayleigh scattering emissions from the sunlit Earth means that useful data can be collected at any local solar time. This extends the useful spectral range into the visible as well. It also enables studies of the Venus circulation, comet



Standard Atmosphere ModTran™ model for transmission (upper plot) and downwelling radiance (lower plot) from 14K feet (blue), 40K feet (green), and 127K feet (red).

characterization (gas/dust ratio, production rates, etc), and characterization of planetary aurorae.

Near Infrared (fully accessible 2.5 – 5 μm): Altitude is extremely advantageous. The telluric methane and water lines are almost completely absent and transmission exceeds 70% within the CO_2 band, so that the entire NIR spectrum is available and with considerably lower downwelling radiance than at lower altitudes, enabling longer observing for dim objects.

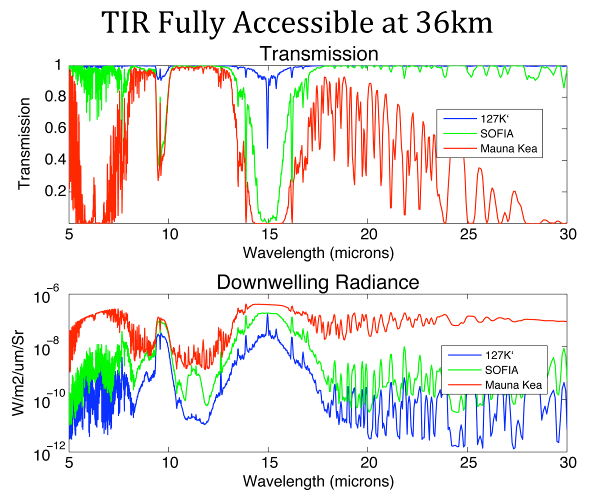
1. BEST (a white paper to the Astronomy 2010 Decadal survey, Lead: Swain). The Balloon-borne Exoplanet Spectroscopy Telescope (BEST) is a balloon mission concept to characterize the atmospheres of exoplanets using molecules such as H_2O, CH_4, and NH_3 as probes. Following an approach for exoplanet molecular spectroscopy demonstrated with Hubble (Swain et al. 2008; Swain et al. 2009) and Spitzer (Grillmair et al. 2008), BEST separates the star and exoplanet light by compiling spectral light curves of a spatially unresolved extra-solar system. This approach requires high photometric stability, making it necessary to place the telescope above the variable and absorbing portion of the Earth's atmosphere. BEST employs a 1.5–5 μm infrared R ~1500 spectrometer, fed by meter-class telescope with a pointing of ~1″ rms.

2. SIPS (a proposal to the Planetary Astronomy program. Lead: Hibbitts). The Stratospheric Infrared Planetary Spectrometer (SIPS) is a balloon-borne mission to conduct near-IR (~ 2.35 – 4.7 μm, 10-nm spectral resolution) observations of airless bodies in our solar system to detect and characterize the IR absorption bands due to volatile and organic materials on their surfaces otherwise obscured by telluric absorptions. The measurements are sensitive to bound water, water ice, hydroxylated and hydrated minerals, ammoniated minerals, organics (volatile and refractory C-H and CN compounds, etc.), and to ices N_2, ammonia, CO_2, etc. on far outer solar system bodies. Hundreds of objects of interest (asteroids, irregular satellites) are constantly available. A 1m+ aperture and ~ 1" long-term pointing stability would likely be needed for the spectroscopy of small outer satellites (such as Triton), Centaurs, and KBOs as well the closer-in main belt and Trojan asteroids.

Thermal-IR (fully accessible 5 – 40 μm and longer):

1. Thermal emission profiles of small airless bodies. Thermal emission curves are informative on the surface roughness and thermal effects that may be important for small airless bodies. Measuring these effects require observations over the season of the body

and can be met with short-term individual observations repeated over months or years. Precise temperature measurements derived from multispectral measurements are needed to acquire and demix the low (~ 150K or lower) and high temperature (~ 400K) components of these subpixel observations, for which a meter-class aperture and arcsec pointing are also needed. Additionally, the weak Christensen features and the silicate reststrahlen bands from ~ 7 – 11 μm, which tend to be low contrast on airless bodies, are informative of specific silicate mineralogy and potentially more accurate than other bands at shorter wavelengths.



At 36 km, transmission is nearly 100% throughout the TIR and downwelling radiance is several times less than at 40K', and orders of magnitude less than at Mauna Kea. O_3 and CO_2 minimally absorb.

Targets of Opportunity:

1. NEAs and comet apparitions. An advantage of many ground-based observatories is the ability to conduct target-of-opportunity observations such as of new comet apparitions or the discovery of an impending close approach by an NEA. With the proposed facility-class capability, existing instruments, stored at PI institutions, could be called up for flight on the HAB gondola. A response time of few months for an initial flight and a turn-around of days or weeks for a repeated flight could be achieved, thus enabling a better characterization of both comets and NEAs.

V. Design Considerations

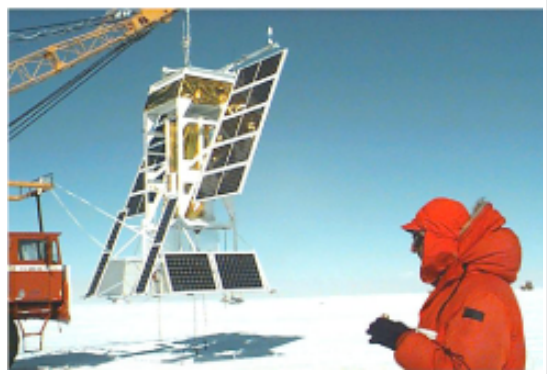
Example Mission Measurement and Operational Desires. The example missions suggest stringent measurement and operational desires associated with the application of HAB to planetary science problems. It would be the role of a NASA-funded working group to determine these requirements and the ability of HAB to meet them. The various example missions' observing goals sum to the ability to observe faint, often small, objects from low to high spectral resolution over wavelengths that encompass those inaccessible from the ground, and sometimes for extended observation and sometimes for repeated short-term observations. Essentially, planetary missions would desire observing stability of 1" or better and an aperture of 1 meter, with larger preferred. Operationally, both long and short-duration missions would be potentially desired, with an initial response time as short as a few months and a turn-around between repeated missions on the order of weeks.

Current Capabilities of Balloon Program. Successful astrophysics and heliophysics balloon missions demonstrate that measurement requirements for planetary science observations can be met.

1. Operational: A rapid mission cadence can be supported if the HAB platform were available. Three missions/year are now standard from McMurdo, several more from US sites, and now Kiruna, Sweden, can support several long duration missions each year. For

this year alone, from McMurdo (winter): BARREL, CREAM, and SPB; from Ft. Sumner (fall): GRINDLAY, HASP, SOFIA, STO; and from Kiruna, Sweden (summer): AESOP, LEE, Sunrise, and ULDB test. Sunrise and AESOP were launched within 2 days of each other and these launch facilities can support a rapid mission cadence of a healthy planetary science balloon program. Gondola (not platform) reuse has been demonstrated by several missions, although significant refurbishment was required after each mission, and mission cadence was slower than desired for a robust planetary science capability – about a 2-year turn-around. For instance, the Solar Bolometric Imager and Flare Genesis used the same gondola, (Bernasconi et al., 2004). And the Stratospheric Terrahertz Observatory, scheduled for launch from McMurdo in 2010 (Walker et al., 2008), will reuse the Flare Genesis Mission gondola and telescope. CREAM demonstrated very long duration capability from McMurdo with a 42-day mission from Dec 2004– Jan 2005. CREAM has launched twice since then (2005, 2007) after gondola rebuild and is scheduled for a fourth launch in 2009. In part, these slow mission cadences are driven by the need to refurbish a gondola to repair damage sustained upon 're-entry'. On the other hand, the current reuse of gondolas points to the potential for a high barrier to entry for any new planetary science balloon program without having a highly-capable facility platform maintained by NASA. An increased mission cadence would also dramatically broaden participation while increasing mission cadence, thus increasing the opportunities for training the next generation of scientists, engineers, and managers.

2. Measurement: Past missions have demonstrated the potential to achieve the measurements called for by the example mission concepts, specifically pointing precision and stability required for a large aperture telescope. For example, SUNRISE, launched from Kiruna, Sweden, in 2009, using a 1-meter solar telescope to provide near diffraction-limited images of the Sun. The gondola provided fine pointing to 7.5" that the instruments improved that to an incredible 0.05". Significantly longer ago, Stratoscope II achieved a pointing accuracy of 15–50 milliarcsec on stars in 1968 using a two-level control system (McCarthy 1969). The BLAST mission in particular has demonstrated the ability to fly large telescope with a 2-m aperture with flights in 2003, 2005, and 2006, although without sufficiently precise pointing for most planetary science applications.



Flare Genesis gondola in Antarctica, 2000 (Walker et al., 2008)

VI. Technology Needs and Challenges

The current capabilities of the balloon program do not fully meet the needs of a healthy planetary science program; individual balloon flights are currently too costly and occur at too long an interval. However, the technology development required to achieve and maintain a robust and vibrant planetary science suborbital balloon program is small. Below are areas identified as potentially needing additional development.

Precision Pointing: The development of precision-pointing technology for a facility

platform is both required and possible. The Wallops Arcsecond Pointer (WASP) zero-stiction gimbal mount and its control system offer a good first level of precision control. The WASP has performed to sub-arcsecond levels in a hang-test configuration in the laboratory and needs to be brought to a level of readiness for balloon-flight by integrating both the star tracker and flight payload and conducting further hang tests.

Large Telescope Capability: Large (1+ or 2-m) telescopes are desired to take full advantage of the benefits of observing from high altitude. Wallops facility is funding a study of the science need and technological challenges of large aperture (2-4m) telescopes from a balloon platform. A ~ 2-meter telescope capability with precision pointing would enable balloon-borne platforms to compete head-to-head with space-based platforms for solar system objects and to potentially exceed current airborne capabilities.

Rapid Mission Cadence: A rapid turn-around enabled by mitigating payload damage during recovery is desired. An impact speed of 21 feet/sec (equivalent to falling from a second story of a building) inevitably causes structural damage to the gondola and possibly payload damage, which reduces turnaround to months or years. A platform supporting a rapid mission cadence would likely require a landing protection system that prevents even this minimal damage, as well as providing more protection for the payload, which would also decrease the cost in returning the platform to use. Additionally, an active planetary science balloon program will increase balloon mission cadence, and these additional launches may require additions to the current infrastructure.

Ultra Long Duration Balloon: New super-pressure balloon technology can enable mission durations of 100 days. The goal of that NASA program to develop a 22 million-cubic-foot balloon that can carry a one-ton instrument to an altitude of more than 110,000 feet would enable unique science measurements and should continue to be a high priority.

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